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OPTIMIZATION FOR ARMS ANGLES OF SCRUB NURSE ROBOT USING FUZZY LOGIC CONTROL SYSTEM

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ABSTRACT

In the present paper, a nonlinear dynamic model representing scrub nurse robotic manipulator was developed. The mathematical model considers the different motions of robot arms. The Scrub Nurse Robotic manipulator (SNR) consists of two links, end grabber, moving base connected to stationary base, four revolute joints, speech recognition and image processing systems. The model considers the simultaneous rotational motions of links and joints. The correct distribution of links' masses helped in decreasing joint's motors' torque. Robot links' movements controlled by Arduino control system and the links' angles values verified through using fuzzy logic control system.

KEYWORDS: Robotic Scrub Nurse Manipulator, Mathematical Model, Torque, Links Angle, Arduino & Fuzzy System

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Original Article

INTRODUCTION

Robotics is a new field of technological advancement that addresses the connection of perception to motion and wherever this connection is intelligent, artificial intelligence plays a key role in robotics, Francis P. et al., 2006.

The robotic nurse can build complete picture about how, why, and when robotic system was used. It helps human scrub nurses during surgical operations. It also solves problems of human nurse with in a faster and accurate manner.

With the usage of scrub nurses robotic, the problems like accuracy, speed and quality in dealing with surgical equipment's and instruments had solved, Nayeemuddin M. et al., 2013.

The Fanuc LR Mate 200iB model of scrub nurse robot was modified electrically by adding new connector devoted to electromagnetic gripper control, C. Perez-Vidal et al., 2012.

Quirubot nurse model robot equipped with speech recognition module recognizes requested surgical instruments, the surgical equipment's and elements located on storage tray. Today, the scrub nurse robot can pick or placed the required element from or on the tray respectively depending on computer vision and pattern recognition.

The robotic nurse acquires and maintains current knowledge on best-practice nursing rules for robotic surgery by understanding the operation and helps improving the overall flow. Management of the unanticipated circumstances for caring patient's can be done easily using robotic nurse with safety and high quality, Ali A.

Raheem et al., 2017.

Robotic scrub nurse plays very important role in operating room. In this study, speech and gesture modalities system was implemented after testing. Also, the average instrument acquisition times was tested and compared, Mithun G. Jacob et al., 2012. The multimodal system responded faster than the unimodal systems.

Pushkal B. et al., 2018 studied a kinematic and dynamic modeling for two links planar robot manipulator. These types of planer robot were taken as an example like robotic nurse system with two degree of freedom. The mathematical formulation for calculating position, speed and acceleration of the robot gripper was derived. Also, the position, speed and acceleration of the links related to frame base were determined through Denavit-Hartenberg parameters (convention and homogeneous matrices) kinematics and dynamics formulas. All these equations and calculations were done by implementing the MALAB software to design a code for developing, simulating results, and stating analysis plotting.

Arduino is open-source microcontroller development board (Mithun G. Jacob et al., 2013, Wachs et al., 2011, Joelle P. et al., 2003) which contains programmable circuit board and includes software. It reads and control sensors, motors, lights and several measuring applications.

Artificial intelligence, especially fuzzy logic control system is the easier model that is essential for the development of human to predict, verify and optimize the solution of problems. Mark J. Wierman, 2010. Fuzzy system rules base control system in this process controls the inputs to obtain the required outputs with ease and accuracy. There is an analogous form of in mathematics, where a complicated problem was solved in the complete plant.

Fuzzy logic control is used to replace an expert human operator depending on fuzzy rule-based control system, Sherif K. Hussein et al., 2014. They used analogous form of in mathematics for solving the problem in plant. Using fuzzy logic control system ensures excellent study and guarantees the operation of interconnected power system.

Implementation of fuzzy logicis is easy in its usage as it does not need derivative knowledge or complex mathematical equations, Zafer B. et al., 2010 By using fuzzy logic control system parallel to traditional control techniques, it improves robustness and efficiency of the nurse robot system, Kshetrimayum L. et al., 2014.

Alexander C. et al., 2018, used fuzzy logic control system for controlling the movements of robot arms and joints. The membership functions applied to see the actual effect on the robotic arms. Color-clustering technique was used for improving machine vision system to discriminate between colors without confusion.

In the present work, a review of two degree of freedom robot is discussed in section 1. Then, a scrub nurse robot was designed and implemented with an Arduino-based control system as explained in section 2. Section 3 include the mathematical model that was created for this robot to calculate the torque required for moving the robot links and joints and the equations of motion. Optimization of links angles related to links dimension was done using fuzzy logic system in section 4. The Arduino control system and fuzzy logic control system results are discussed in section 5.

EXPERIMENTAL WORK

SNR (Scrub Nurse Robot) as shown in figure 1 is used for performing the function of the human nurse with more accuracy and precision. As shown in figure 2, the robot work begins when the surgeon requests a specific surgical instrument. Through speech recognition system, the surgeon passes order to the robot, and then arms started to move against order of Arduino control system. The scrub nurse robot uses a webcam to determine the tool image. The image processing for

template matching is done through image processing code. The final stage of the process is the picking of instrument from tray by gripper and passing on it to surgeon.

Figure 1: Scrub Nurse Robot.

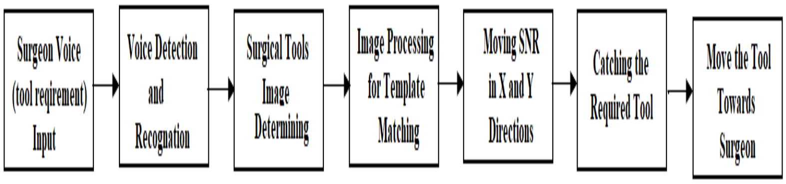


Figure 2: SNR Process Sequences.

Scrub nurse robot contains three arms, four joints, stationary base and gripper. Image acquisition device (webcam) and voice detection system (speech recognition) for SNR runs through shields of Arduino. The movement of scrub nurse robot arm is controlled by Arduino Mega microcontroller board. A C++ software code for the Arduino control system had created for controlling the SNR components movements.

EQUATIONS OF MOTION

SNR was built with three links jointed with three revolute pairs as shown in figure 3. Scrub nurse robot motion considered as $\theta_i\,;\, i\ =\ 1,2,3,4,5,$, first three angles for robot arms movement and the last two for moving gabber angles. Lagrangian approach is used for robot arms dynamic equations. Kinetic and potential energy of robot arms are obtained from the following equations

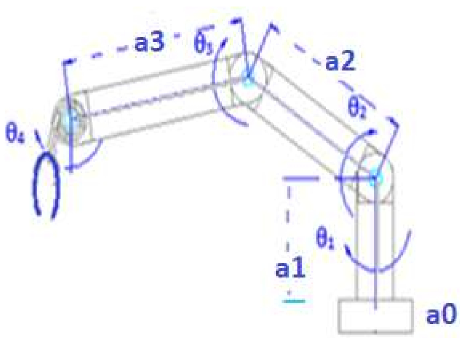


Figure 3: Coordinates of Robot.

The robot links dimensions, joints rotating angles and motors torque specifications are explained in Table 1.

Table 1: Parameters of the Scrub Nurse Robot

Parameter	Link 0 (Stationary Base)	Link 1 (Moving Base)	Link 2	Link 3	Gripper
Mass (m) kg	1.5	2.00	2.00	1.50	0.25
Length (L) m	0.15	0.15	0.50	0.35	0.13
Link angle	0^0	270^0	150^0	135^0	75^0
Motor Torque (T) N.m	0 N.m	2.5 N.m	2.5 N.m	2.5 N.m	2.5 N.m

The robot arms have uniform cross sections and mass per unit length, length of each element *I* denoted by (ρ_i , and a_i) respectively. The equations of motion for the scrub nurse robot arms are related to Lagrangian dynamics approach obtained from

$$\frac{d}{dt}\left(\frac{\partial KE}{\partial \dot{\theta}_i}\right)-\frac{\partial KE}{\partial \theta_i}+\frac{\partial PE}{\partial \theta_i}=\tau_i \tag{1}$$

Where;

$i = 1,2,3,4,5$

τ_i , is torque applied at joint *i*.

$$KE = KE_1 + KE_2 + KE_3 + KE_4 \tag{2}$$

$$KE = \frac{1}{2}J_1\dot{\theta}_1^2 + \frac{1}{6}\rho_2 a_2^3\left(\dot{\theta}_2^2 + \dot{\theta}_1^2\cos^2\theta_2\right) + \frac{1}{2}\left(J_{11}\dot{\theta}_1^2 + J_{22}\dot{\theta}_2^2 + J_{33}\dot{\theta}_3^2 + 2J_{23}\dot{\theta}_2\dot{\theta}_3\right) + \frac{1}{2}M_G\left[u^2 + v^2 + w^2\right] \tag{3}$$

$$PE = PE_1 + PE_2 + PE_3 + PE_4 \tag{4}$$

$$= \frac{1}{2}\rho_2\, g\, a_2^2 s_2 + \rho_3 g\left(a_3 a_2 s_2 + \frac{1}{2}a^2{}_3 s_{23}\right) + M_G\, g\,(a_2 s_2 + a_3 s_{23}) + M_G\, g l\,(1 - c_4 c_5) \tag{5}$$

Equations of motion associated with generalized coordinates $\theta_i, i = 1,2,...,5,$ obtained as follows

$$\sum_{i=1}^{5} A_{1i}\ddot{\theta}_i + \sum_{i,j=1,2}^{5} C_{1ij}(\theta_i,\theta_j)\dot{\theta}_i\dot{\theta}_j = \tau_1 \tag{6}$$

$$\sum_{i=1}^{5} A_{2i}\ddot{\theta}_i + \sum_{i,j=1,2}^{5} C_{2ij}(\theta_i,\theta_j)\dot{\theta}_i\dot{\theta}_j + D_{22} = \tau_2 \tag{7}$$

$$\sum_{i=1}^{5} A_{3i}\ddot{\theta}_i + \sum_{i,j=1,2}^{5} C_{3ij}(\theta_i,\theta_j)\dot{\theta}_i\dot{\theta}_j + D_{33} = \tau_3 \tag{8}$$

$$\sum_{i=1}^{5} A_{4i}\ddot{\theta}_i + \sum_{i,j=1,2}^{5} C_{4ij}(\theta_i,\theta_j)\dot{\theta}_i\dot{\theta}_j + D_{44} = 0 \tag{9}$$

$$\sum_{i=1}^{5} A_{5i}\ddot{\theta}_i + \sum_{i,j=1,2}^{5} C_{5ij}(\theta_i,\theta_j)\dot{\theta}_i\dot{\theta}_j + D_{55} = 0 \tag{10}$$

$$A_{11} = \begin{bmatrix} J_1 + \frac{1}{3}\rho_2 a_2{}^3 c_2^2 + J_{11} + \\ M_G \begin{Bmatrix} l^2(c_{23}s_4s_5)^2 + l^2(s_{23}s_4s_5)^2 \\ +(a_2c_2 + a_3c_{23} - ls_4c_5)^2 \end{Bmatrix} \end{bmatrix} \tag{11}$$

$$A_{12} = A_{21} = M_G \begin{Bmatrix} -l(c_{23}s_4s_5)a_2s_3 \\ +l(s_{23}s_4s_5)(a_2c_3 + a_3) \end{Bmatrix} \tag{12}$$

$$A_{13} = A_{31} = M_G l a_3 (s_{23}s_4s_5) \tag{13}$$

$$A_{14} = M_G \begin{Bmatrix} -l^2(s_{23}s_4s_5)(s_{23}c_4c_5 - c_{23}s_4) \\ -l(c_4s_5)(a_2c_2 + a_3c_{23} - ls_4c_5) \end{Bmatrix} \tag{14}$$

$$A_{15} = M_G \begin{Bmatrix} l^2(c_{23}s_4s_5)^2 + l^2(s_{23}s_4s_5)^2 \\ -l(s_4c_5)(a_2c_2 + a_3c_{23} - ls_4c_5) \end{Bmatrix} \tag{15}$$

$$A_{22} = \begin{bmatrix} \frac{1}{3}\rho_2 a_2{}^3 + J_{22} \\ +M_G\left\{(a_2s_3)^2 + (a_2c_3 + a_3)^2\right\} \end{bmatrix} \tag{16}$$

$$A_{23} = A_{32} = J_{23} + M_G a_3 (a_2c_3 + a_3) \tag{17}$$

$$A_{24} = M_G \begin{bmatrix} a_2s_3 l(c_{23}c_4c_5 + s_{23}s_4) \\ -l(a_2c_3 + a_3)(s_{23}c_4c_5 - c_{23}s_4) \end{bmatrix} \tag{18}$$

$$A_{25} = M_G \begin{bmatrix} -a_2s_3 l(c_{23}s_4s_5) \\ +l(a_2c_3 + a_3)(s_{23}s_4s_5) \end{bmatrix} \tag{19}$$

$$A_{33} = \left[J_{33} + M_G a_3^2\right] \tag{20}$$

$$A_{34} = A_{43} = -M_G a_3 l(s_{23}c_4c_5 - c_{23}s_4) \tag{21}$$

$$A_{35} = A_{53} = M_G a_3 l(s_{23}s_4s_5) \tag{22}$$

$$A_{44} = M_G l^2 \begin{bmatrix} (c_{23}c_4c_5 + s_{23}s_4)^2 \\ +(s_{23}c_4c_5 - c_{23}s_4)^2 + (c_4s_5)^2 \end{bmatrix} \tag{23}$$

$$A_{45} = M_G l^2 \begin{bmatrix} -(c_{23}s_4s_5)(c_{23}c_4c_5 + s_{23}s_4) \\ +(s_{23}s_4s_5)(s_{23}c_4c_5 - c_{23}s_4) \\ +(s_4c_5)(c_4s_5) \end{bmatrix} \tag{24}$$

$$A_{55} = M_G l^2 \left[(c_{23}s_4s_5)^2 + (s_{23}s_4s_5)^2 + (s_4c_5)^2 \right] \tag{25}$$

$$D_{11} = 0$$

$$D_{22} = \frac{1}{2}\rho_2 g\, a_2^2 c_2 + \rho_3 g \left(a_3 a_2 c_2 + \frac{1}{2} a^2{}_3 c_{23} \right) + M_G g (a_2 c_2 + a_3 c_{23}) \tag{26}$$

$$D_{33} = \rho_3 g \left(\frac{1}{2} a^2{}_3 s_{23} \right) + M_G g a_3 c_{23} \tag{27}$$

$$D_{44} = M_G gl\, s_4 c_5 \tag{28}$$

$$D_{55} = M_G gl\, c_4 s_5 \tag{29}$$

FUZZY LOGIC WITH LINKS ANGLES

Fuzzy logic controller as shown in figure 4, built from fuzzifier block, converts real-world crisp values to fuzzy sets through membership functions (three membership functions of the links and gripper dimensions. Inference engine to interprets the input fuzzy set based on fuzzy rules to decide the output fuzzy sets (if then rules for inputs and outputs conditions). Defuzzifier block converts fuzzy output into real-world crisp values (output decisions of the fuzzy logic control system), S. Sarkar et al., 2009. The fuzzy logic control system dictates the amount and direction (angles) of links movements by controlling the links servo motors torques.

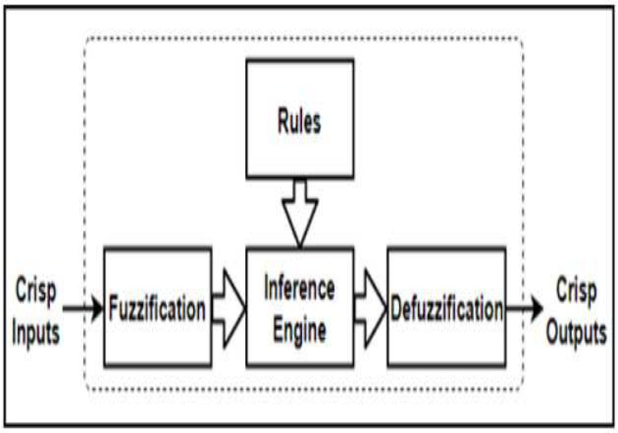


Figure 4: Fuzzy Logic System Structure.

Figures5, 6 shows the fuzzy logic system controlling the robot arms movement. The fuzzy logic system has five inputs (dimensions of links and servomotors torque) and four outputs (angles of links movements). Three membership functions with three levels (low, medium and high) used for fuzzification inputs and defuzzification outputs.

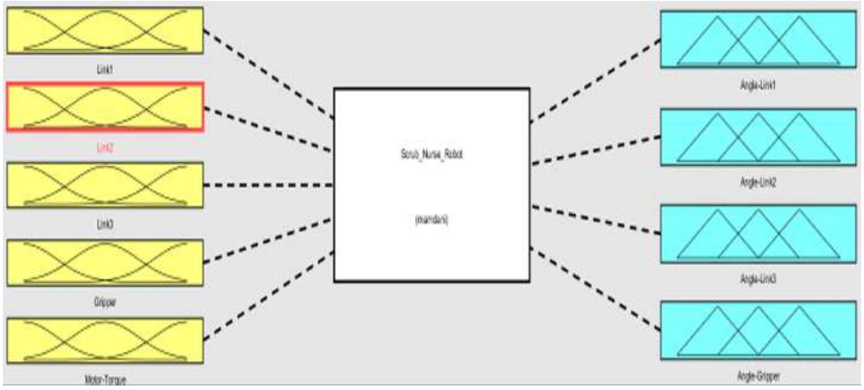
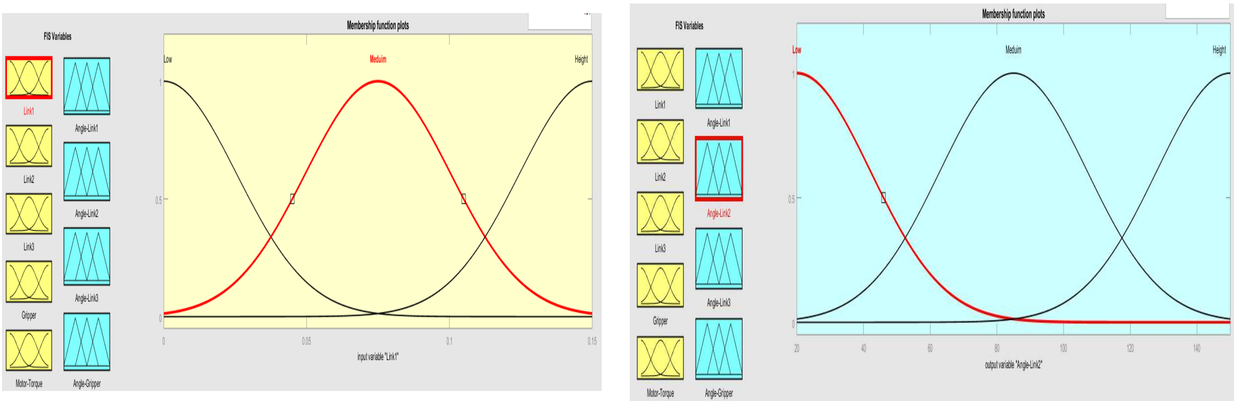


Figure 5: Inputs and Outputs of Fuzzy System.



(a) **(b)**

Figure 6: Gauss Membership Function for Inputs (a) and Outputs (b).

If-than rule is implemented for optimizing the values of outputs, as shown in figure 7, according to changes in links dimension.

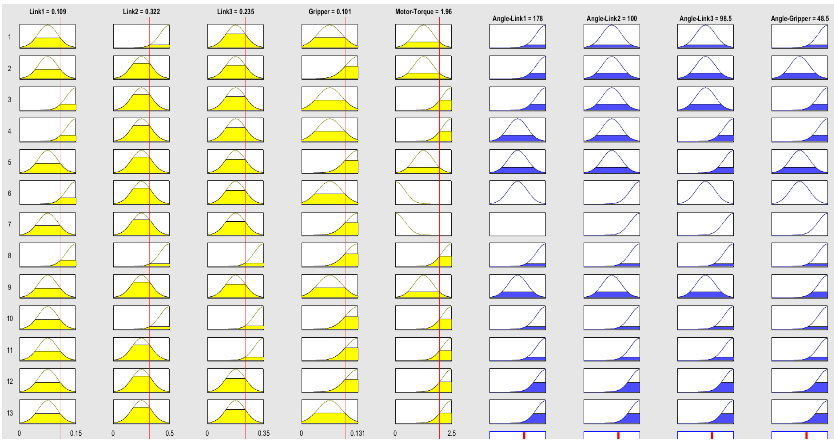


Figure 7: Optimaize the Output for Inputs.

The maximum em values of links angles related to change in input linkes dimenstions is given in Table 2.

Table 2: Values of Maximum and Minumem of Inputs-Outputs Values

Dimenstions (m)	Inputs					OutPuts			
	Motor Torque	Link 1	Link 2	Link 3	Gripper	Angle Link 1	Angle Link 2	Angle Link 3	Angle Gripper
Maximum Values	2.10 N.m	0.12	0.41	0.26	0.12	170^0	95.6^0	95^0	47.3^0
Minumum Values	0.71 N.m	0.04	0.1	0.04	0.012	150^0	85^0	87^0	41.5^0

CONCLUSIONS

In the present work, a scrub nurse robot with two basies, two links, gripper (end effector) and three jointes are studied. A mathematical model for three degree of freedom robot was designed. The Lagrangian equation depending on Lagrangian dynamics approach was applied on equations of motion for the arms of robot to calculate angles for each link and determine the torque required for each joint. Arduino Mega microcontroller board with C++ software code was used to control the SNR components movements. To determine the maximum and minimum values of arm links, gripper angles dimensions, a fuzzy logic control system was designed with five inputs (length of two links and servomotors torque value for each joint) and four outputs (angles of each link movement) for predicting speed and position of robot arms related to angles of joints and torque's of motors.

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